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PROCESS AND APPARATUS FOR PRODUCTION OF ULTRASHORT-CUT FIBERS

FIELD OF THE INVENTION

The present invention relates to a process for production of ultrashort-cut fibers whereby numerous yarns composed of long individual filament groups are bundled to make a paralleled fiber bundle, and the fiber bundle is cut to produce ultrashort-cut fibers having a fiber length of no greater than 1 mm, as well as to an apparatus therefor.

BACKGROUND ART

Staple fibers with lengths of from several millimeters to several tens of millimeters have conventionally been obtained by bundling filaments made of thermoplastic synthetic positive such as polyesters or polyamides into a fiber bundle, and cutting the fiber bundle. The cutting apparatus used has been, for example, a roller cutter type fiber bundle cutting machine which winds the fiber bundle on a cutter roller provided with a plurality of cutting blades arranged in a radial fashion, and presses the fibers wound on the cutting blades against the cutting blades while continuously cutting them to the prescribed length. There have also long been known apparatuses called guillotine cutter type fiber bundle cutting machines, which are provided with a fixed blade and a moving blade as shear blades and accomplish cutting by pressing the fiber bundle against the shear blades at a prescribed cutting length.

While such fiber bundle cutting machines have been conventionally used, recent years have seen increased demand for very short synthetic fibers for inclusion into certain types of cosmetics, for microfibers used in soft flocked

products or for shortly chopped elastic fibers. Staple fibers having cut fiber lengths of between 0.1 mm and several mm have therefore been required.

Incidentally, when using the above-mentioned roller cutter fiber bundle cutting machine, for example, it has been necessary to use very small spacings between the adjacent cutting blades of the cutting blade group arranged radially on the rotating cutter roller. This has resulted in clogging of the cut fibers between the cutting blades which hinders ejection of the fibers, while problems with the thicknesses of the cutting blades themselves have posed a limit on the shortness of the cut fiber lengths.

On the other hand, a guillotine cutter type fiber bundle cutting machine can handle cut fiber lengths of about 0.5 mm. Still, when it is attempted to use conventional types of fiber bundle cutting machines to cut long, thin fibers with a small individual filament size, the elasticity of the filaments themselves results in bending of the filaments, causing them to buckle or contact with the fixed blade at right angles. In addition, it is extremely difficult to adjust the clearance between the fixed blade and moving blade, resulting in miscutting such as slanted cuts or uneven cutting lengths.

Thus, when it is attempted to obtain staple fibers with consistent fiber lengths, the properly cut fibers must be selected and removed from among the many miscut fibers. However, the selection and removal operation is not only very complex, but the yield of properly cut fibers is also impaired if large numbers of miscut fibers outside of the permissible cutting length range are present.

Apparatuses have therefore been proposed, such as in Japanese Unexamined Patent Publication No. 2003-119662, which overcome the above-mentioned problems of guillotine cutter type fiber bundle cutting machines. According to this prior

art, a guide is mounted upstream from the cutting zone of the continuously supplied filament bundle, in order to wrap the supplied fiber bundle with a continuous sheet-like member. After being laid so that the filament bundle running with the continuous sheet-like member which travels with the fiber bundle becomes wrapped via the guide roller, the fiber bundle wrapped with the sheet-like member is cut. That is, wrapping the fiber bundle, which by itself alone is originally flexible and difficult to cut, with the sheet-like member stiffens it, and the stiffened fiber bundle is then cut to achieve cutting into staple fibers of the prescribed length.

However, even this guillotine cutter type fiber bundle cutting machine is only able to cut to fiber lengths of 0.1-30 mm, and it is very difficult to stably obtain cut fibers of smaller than 0.1 mm at a high yield. Furthermore, the sheet-like member used to cover the fiber bundle to obtain such staple fibers must be paper, an organic polymer film such as polyolefin, polyester or cellophane, a cloth, a nonwoven fabric or the like.

Also, when such a sheet-like member is used, the cut fibers and the sheet-like member must be separated after cutting. Accomplishing complete separation is difficult, and trace amounts of cutting scrap can be included in the cut fibers. In addition, as the cut fiber length approaches 0.1 mm, the fiber bundle must be bound more into a more rigid form to accomplish cutting more reliably. This has required the sheet-like member to have even greater stiffness, which has naturally placed limits not only on the materials that can be used but also on their handling.

Thus, since vastly lower yields due to miscutting are compounded by reduced productivity, it has been difficult in practice to obtain staple fibers with cut fiber lengths of no greater than 0.1 mm. Furthermore, when staple fibers are

produced in bulk in order to increase productivity, it is necessary to maximize the fiber bundle thickness by bundling large numbers of multifilament groups. Yet, a thicker fiber bundle leads to weaker binding force on the individual filaments inside the fiber bundle, even if the fiber bundle is wrapped around by a film-like sheet and a strong binding force is applied. With the binding force weakened, the fiber bundle comprising the individual filament groups which are in a freely, even if only slightly, movable state, cannot be easily cut to a short length.

In other words, when each individual filament is removed from the individual filament group composing the fiber bundle, since each individual filament is very thin at, for example, 0.001-10 dtex and highly elastic, it is therefore easily deformed in the direction of the force from the cutting blade during cutting and escapes from the cutting blade. As a result, it is very difficult to properly cut the fiber bundle to a very short length of no greater than 0.1 mm at a satisfactory yield without miscutting.

Examining the prior art from the standpoint of binding and cutting fiber bundles, it is found that, for example, Japanese Unexamined Patent Publication SHO No. 63-35829 proposes cutting aramid fibers which are difficult to cut with conventional cutting machines. This prior art is a technique whereby a molten thermoplastic resin is impregnated into aramid fibers and cured, and the cured resin is pelletized, together with the fibers, using a pelletizer. However, this prior art was developed to obtain fiber-reinforced plastic having short cut fibers kneaded therein, without requiring removal of the impregnated thermoplastic resin from the cut fiber bundle. Thus, the technique does not isolate the cut fibers alone for their removal from the thermoplastic resin, and removal is completely irrelevant. Furthermore, this prior

art accomplishes pelletizing after impregnation of the thermoplastic resin in the fibers as mentioned above, and it is very difficult to pelletize fiber-containing resin cut to lengths of no greater than 0.1 mm using known pelletizers.

Also, in terms of productivity of the ultrashort-cut fibers, a very large number of long thin individual filaments are bound to form a fiber bundle with a overall size exceeding 10,000 dtex, and these must be bound with the thermoplastic resin. However, it is also difficult to sufficiently impregnate such a thick fiber bundle, through to its interior, with a high-temperature thermoplastic resin having a high melt viscosity. Consequently, even though the thermoplastic resin is impregnated into the fiber bundle, it has not been possible to avoid partial production of individual filament groups which cannot be bound with the thermoplastic resin inside the fiber bundle. As a result, individual filament groups not sufficiently bound by the thermoplastic resin are produced, and miscutting is unavoidably increased.

SUMMARY OF THE INVENTION

It is an object of the present invention to overcome the problems of the prior art described above, by providing a process and an apparatus which allow stable production of ultrashort-cut fibers having fiber lengths of no greater than 0.1 mm while minimizing miscutting. Throughout the explanation of the invention which follows, the terms "embedding agent" and "embedding material" are used, with the term "embedding agent" referred to a liquid state or gaseous state, and the term "embedding material" referring to a solid state.

As a result of much diligent research directed toward achieving the object stated above, the present inventors have discovered that it is difficult to obtain cut fibers with very

short fiber lengths of no greater than 0.1 mm by the technical concept of "fiber bundle cutting" according to the prior art. Specifically, when a single individual filament of the individual filament group of the fiber bundle is removed, the individual filament is very thin and highly elastic. Consequently, the individual filament to be cut readily deforms by the force from the cutting blade during cutting and escapes from the cutting blade. As a result it was discovered that, even if not impossible, it is very difficult to properly cut the filament to a very short length of no greater than 0.1 mm at a satisfactory yield without miscutting.

In the course of trial and error while experimenting with various concepts aimed at solving this problem, it occurred to the present inventors that it might be possible to obtain ultrashort-cut fibers of 0.1 mm not by "fiber bundle cutting" but rather by "fiber bundle shaving". However, this raised the problem of how to shave a fiber bundle consisting of numerous bound single thin individual filaments. It was then imagined that a very satisfactory shaving material might be obtained by integrating an embedding step whereby the fiber bundle is embedded, through to its interior, in an embedding material such as paraffin, resin or ice.

The present invention therefore provides a process and an apparatus which allow stable production of ultrashort-cut fibers having fiber lengths of no greater than 0.1 mm (especially 0.005-0.1 mm) while minimizing miscutting. Specifically, the invention provides a process and apparatus whereby a fiber bundle is formed by binding numerous individual filament groups, an embedding material which is solidified by cooling and gasified or liquefied by heating is gasified or liquefied, the fiber bundle is embedded with the gasified or liquefied embedding material to prepare a shaving material, and the edge of the shaving material is thinly

shaved at a temperature at which the embedding material does not gasify or liquefy, to obtain ultrashort-cut fibers having cut fiber lengths of no greater than 1.0 mm.

We examined the fact that for the process and apparatus for production of ultrashort-cut fibers with no miscutting, it is essential for the fibers embedded in the embedding material to be paralleled in one direction. Thus, numerous wound yarns are prepared each comprising a multifilament yarn composed of numerous individual filament groups. The yarns are then wound up from the wound yarn group onto a hank winder (winding reel), while doubling each yarn which is unrolled at a constant tension, to prepare a fiber bundle that is lap wound onto the reel and has a prescribed overall size. This forms wound areas within the sections lap wound on the reel wherein the individual filament groups are paralleled to each other in a linear fashion, and it is each of these areas which are utilized. Specifically, they are subjected to an embedding step wherein both ends of each linearly paralleled wound area is set by an embedding agent such as an adhesive, and the set section is cut to create a shaving material. Alternatively, both ends of the linearly paralleled wound area may be held by clamping with a pair of fasteners, adhesive tape or the like while the fiber bundle is cut at both outer ends from the pair of fasteners, to create a fiber bundle which is paralleled in a satisfactorily linear fashion. If it is necessary to produce ultrashort-cut fibers in bulk, the individual filament size is preferably 0.001-10 dtex, and the overall size of the fiber bundle composed of the individual filament groups is preferably 10,000-10 million dtex.

Next, the fiber bundle paralleled in a satisfactorily linear fashion, which has been prepared in this manner, passes to the embedding step; however, residual air is present inside the fiber bundle. The fiber bundle is therefore preferably

allowed to stand in a satisfactorily paralleled state in the embedding container, and subjected to vacuum degassing. The pre-degassed embedding agent in a liquid or gaseous state is then filled into the container and impregnated into the fiber bundle with the fiber bundle surrounded by the embedding agent. Here, the embedding step is preferably carried out while evacuating the container with an exhauster as a vacuum apparatus under slightly negative pressure with respect to atmospheric pressure, to avoid residual air bubbles in the interior. This will prevent almost any air bubbles from forming in the embedded fiber bundle, thus allowing each of the individual filaments of the fiber bundle to be bound together. Thus, fiber bundles which are highly flexible and otherwise readily escape from the shaving blade when no binding force is acting on them are subjected to adequate shaving force which is transmitted when the shaving blade contacts each individual filament. By thinly shaving the embedded fiber bundle in this manner, therefore, it is possible to mass produce ultrashort-cut fibers having fiber lengths of 0.005-0.1 mm without miscutting.

The embedding agent used is preferably water which can be easily and inexpensively obtained in large quantities and is very easy to handle. If water is used, it will readily penetrate to the interior of the fiber bundle due to the low viscosity of water. To facilitate ready infiltration into the interior of the fiber bundle, small amounts of surfactants may be added including, for example, nonionic surfactants such as polyalkyleneglycol esters and ethers, anionic surfactants such as alkali metal salts of fatty acids, alkyl phosphates, sulfonates and sulfates, cationic surfactants such as quaternary ammonium salts and amphoteric surfactants such as alkali metal salts of aminocarboxylic acids, or alkylbetaines or the like, to allow the water to thoroughly penetrate the

interior of the fiber bundle.

It is preferred to avoid using overly thick fiber bundles which are resistant to infiltration by embedding agents such as water, and from which residual air in the fiber bundle interior is difficult to eliminate, and instead to embed numerous small fiber bundles or flat fiber bundles arranged in parallel. This will allow very effective removal of air bubbles included in the shaving material. When the water is frozen, air dissolved in the water will generate bubbles. Gentle heating is therefore performed with heating means above the cover of the freezing vessel in which freezing (embedding) is carried out. The freezing procedure with the freezing apparatus is preferably carried out in a controlled manner to avoid freezing of the water surface, maintaining reduced pressure above the water surface with a vacuum apparatus, in order to prevent residual air bubbles from the water.

The invention produces ultrashort-cut fibers by shaving in the manner described above, and the shaving means used may be a well-known machine tool such as a planing machine, slotting tool, planing/molding machine or miller, or a modified type thereof. The numerous prepared shaving materials are arranged in a densely parallel state by the process and apparatus described above. These may be again embedded in the embedding material in this aligned state to form an integrated block, which is used as the new shaving material and supplied to the machining bench. This will allow a large volume of ultrashort-cut fibers to be easily produced. Regardless of the means used for shaving of the shaving material, however, insulating means and/or cooling means are preferably provided to cool the holding means holding the shaving material, so that the embedding material forming part of the shaving material does not change from a solid state to a liquid or gaseous state. It will sometimes be preferable

for the shaving blade to be cooled.

The embedding material used for the process and apparatus for production of ultrashort-cut fibers according to the invention as described above is most preferably dry ice or ice, because dry ice or ice has the advantage of allowing the ultrashort-cut fibers easily produced by natural drying, hot air drying or freeze drying to be separated from the thinly shaved shaving material. For conjugated fibers comprising a combination of two different polymers, significant temperature changes can produce dimensional alterations and result in peeling between the combined polymers. Particular care must be taken when drying optical interference fibers such as described in Japanese Unexamined Patent Publication HEI No. 11-241223. This is because such fibers are controlled in such a manner that the thicknesses of the mutually attached polymer layers are on the micron order, so that incident light will interfere with the combined polymers to display a clear shade. In such cases, therefore, it is preferred to using a freeze drying method which allows removal of water while in a frozen state.

BRIEF DESCRIPTION OF THE DRAWINGS

Figs. 1 and 2 are schematic drawings illustrating first and second embodiments for obtaining a fiber bundle prepared for production of ultrashort-cut fibers according to the invention.

Fig. 3 is a pair of drawings showing a concrete embodiment for a process of embedding a fiber bundle F wound using the hexagonal winding reel shown in Fig. 1, wherein Fig. 3(a) is a schematic plan view and Fig. 3(b) is a schematic side view.

Fig. 4 is a schematic illustration (plan view) showing a treatment tank for embedding treatment of a fiber bundle with

an embedding material.

Fig. 5 is a pair of schematic drawings illustrating the state of the embedding treatment in which the winding reel with the fiber bundle wound up thereon is immersed in a treatment tank filled with a liquefied embedding agent, wherein Fig. 5(a) is a schematic plan view and Fig. 5(b) is a schematic side view.

Fig. 6 is a schematic side view showing the state after the liquefied embedding agent has been cooled to solidity and then removed out of the treatment tank.

Fig. 7 is a schematic illustration (plan view) showing an embodiment of embedding treatment carried out with the fiber bundle cut out from the winding reel.

Fig. 8 is a schematic side view showing a jig for application of a prescribed tension without causing significant deformation of the fiber bundle when it is removed from the winding reel.

Fig. 9 is a schematic illustration showing embedding treatment of fiber bundles.

Fig. 10 is a pair of cross-sectional views along line A-A of Fig. 9, wherein Fig. 10(a) is an example of a group of small fiber bundles with rectangular cross-sections, and Fig. 10(b) is an example of circular cross-sections.

Fig. 11 is a pair of schematic illustrations showing the maximum required infiltration distance as the critical distance to allow satisfactory infiltration of the embedding agent into the interior of small fiber bundles.

Fig. 12 is a schematic illustration showing a process for removal of air bubbles contained in small fiber bundle groups.

Fig. 13 is a simplified schematic configuration diagram showing an embodiment of a fiber bundle freezing treatment apparatus.

Fig. 14 is a simplified schematic configuration diagram

showing an apparatus for production of ultrashort-cut fibers according to the invention.

Fig. 15 is a magnified front cross-sectional view of the essential part of the shaving mechanism section of Fig. 14.

Fig. 16 is a schematic front cross-sectional view to illustrate adjustment of the protruding length of the shaving blade.

Fig. 17 is a simplified schematic configuration diagram showing an embodiment of cooling means for cooling of the shaving blade and the shaving material.

Fig. 18 is a simplified schematic configuration diagram showing a cooling system which effects cooling of the shaving blade utilizing a Peltier element.

Fig. 19 is a schematic plan view showing the layout of numerous shaving materials arranged in an array on a machining bench.

Fig. 20 is a pair of schematic illustrations showing the state of shaving with a plurality of shaving blades situated in parallel, wherein Fig. 20(a) is a schematic front view and Fig. 20(b) is a schematic side view.

DETAILED DESCRIPTION OF THE INVENTION

The ultrashort-cut fibers to be produced according to the invention may be obtained from synthetic fibers composed of a polymer such as a polyester, polyamide or polyolefin, or conjugated synthetic fibers comprising a combination of two or more polymers, and are not particularly restricted. Specifically, they may be obtained from natural fibers such as silk, cotton or hemp, or semi-synthetic fibers such as cellulose fibers or acetate fibers.

Staple fibers cut to fiber lengths of between 1 mm and several tens of millimeters are generally produced by paralleling yarn composed of extremely small individual

filament groups having individual filaments (also referred to simply as filaments) with sizes of 0.001-10 dtex, to arrange them parallel to each other in the direction of the filament lengths, and cutting the bound fiber bundle to short lengths.

The present invention, like this prior art, requires a step of binding a plurality of yarns composed of numerous individual filament groups to prepare a fiber bundle in the process for production of staple fibers. In this preparation step, it is essential to coil up the multifilament yarn in order to bind the fiber bundle in a parallel state in one direction. This is because if the individual filament groups composing the fiber bundle are oriented in a slanted direction and not parallel in one direction, the embedded individual filament groups become set in the slanted direction instead of being set orthogonally to the shaving direction. If this occurs, shaving of the embedded fiber bundle in this state, after embedding treatment of the fiber bundle with the embedding material as described hereunder, will cause the individual filament groups set in the slanted direction to be shaved in the slanted direction instead of in the orthogonal direction.

According to the present invention, this problem is solved by, as a first embodiment, preparing one or more wound yarns which are formed by winding up the multifilament yarns composed of numerous individual filament groups. The yarns are drawn out from the wound yarns and lap wound on a winding reel such as, for example, a known coiling reel while applying a prescribed tension, to obtain a paralleled fiber bundle. Next, the fiber bundle obtained in this manner is embedded without being removed from the winding reel and while applying the same tension as during winding, so that the tension-applied fiber bundle is embedded and integrated in the embedding material.

Alternatively, as a second embodiment of the invention, both ends of the fiber bundle, which was formed by lap winding the numerous yarns and was wound up in parallel, are completely bound with the same tension applied as during winding. In this case, the binding of both ends of the fiber bundle may be accomplished by wrapping the periphery of the aforementioned ends with adhesive tape to prevent the individual filament groups of the fiber bundle from moving freely, or by holding them with the strong force of a clamp. Also, an adhesive may be impregnated into only the end sections to adhesively anchor together the individual filaments of the fiber bundle.

In this case, unlike the first embodiment, removal from the reel can be accomplished by cutting the tape section anchoring both ends of the fiber bundle, or the adhesively anchored sections. For the removal, if a fixture such as a stretcher is mounted in order to hold both ends of the fiber bundle and allow the tension-applied state to be obtained, removal of the fiber bundle cut from the reel can be carried out with the same degree of tightness without relieving the tension which holds the individual filament groups in parallel.

When a fixture such as a stretcher is not used, the prescribed tension is applied again to both ends of the cut fiber bundle before setting the fiber bundle in the embedding material. In this case, since the individual filament groups are bound in the same position by adhesive tape or the like as described above at both ends of the cut fiber bundle, they can be easily restored to the original satisfactory paralleled state by application of new tension.

Thus, by embedding and integrating the tension-applied fiber bundle in the embedding material, it is possible to uniformly realign the individual filament groups of the fiber bundle in a parallel state when they are set in the embedding

material. Free movement of the individual filaments of the embedded fiber bundle will therefore be completed restricted by the embedding material. As a result, it is possible to produce a state wherein the individual filament groups cannot easily move, being bound by the embedding material, even when the shaving blade contacts the embedded individual filament groups during shaving.

Preferred embodiments of the fiber bundle production process and apparatus for production of ultrashort-cut fibers according to the invention as described above will now be explained in detail with reference to the accompanying drawings.

Figs. 1 and 2 are schematic drawings illustrating two different embodiments for production of ultrashort-cut fibers according to the invention. The embodiment shown in Fig. 1 will be explained first.

In the embodiment of Fig. 1, 1 is a winder, which may be a known hank winder for winding of hanks, and 2 is doubling means composed of a yarn guide or the like. P represents a wound yarn group consisting of one or more wound yarns, and in the illustrated example consists of three wound yarns (P1, P2, P3). Multifilament yarns (y1, y2, y3) composed of numerous filaments (individual filaments) are wound around each wound yarn (P1, P2, P3). Each of the yarns (y1, y2, y3) is guided to the doubling means 2, and after being doubled through the doubling means 2, is wound up on the winder 1.

In this embodiment, the yarns (y1, y2, y3) are reeled onto the winder 1 simultaneously as they are doubled after being unrolled and drawn out from the wound yarns (P1, P2, P3), but the doubling step may also be detached. That is, the system may be designed to unroll and draw out each of the yarns (y1, y2, y3) from the wound yarns (P1, P2, P3) and double them, forming from the doubled yarn y alone a single

wound yarn suitable for supply to the winder 1, and supplying the doubled yarn y to the winder 1. If this type of system is used, the operation can be carried out more efficiently when preparing a plurality of fiber bundles F by a plurality of winders 1, eliminating the need to prepare a plurality of wound yarns (P1, P2, P3) for each winder.

According to the invention, the yarn group y obtained by doubling the yarns (y1, y2, y3) composed of multifilaments (numerous individual filament groups) having individual filament sizes of, for example, 0.001-10 dtex is bound with the filaments arranged in parallel in the direction of the fiber lengths, to prepare a fiber bundle F with an overall size of 10,000 to 10 million dtex. A reel 10 is provided which lap winds the yarn group y supplied from the wound yarn group P onto the winder 1 the necessary number of times, to obtain a fiber bundle F having the prescribed overall size. The reel is provided with winding width controlling members 11 which control the reeling width of the fiber bundle F to the prescribed size.

Referring to Fig. 1, the reel 10 is constructed from a hexagonal frame, and twelve winding width controlling members 11 are provided as shown at the vertices on the hexagonal reel 10. Thus, the doubled yarn group y becomes lap wound as a fiber bundle F on the winding width controlling members 11, without directly contacting the reel 10. For better stability of the winding tension, however, the shape of the reel 10 is preferably a polygonal shape having a greater number of sides than the regular hexagon of this embodiment, although it may also be a regular triangle or square. This hexagonal reel 10 will be referred to for convenience in the explanation of the examples of the invention provided below, but it is understood that the invention is not limited to these examples, as mentioned above.

In the fiber bundle F formed on the reel 10 in this manner, only the sections Fs which are paralleled in a linear fashion suitable for shaving are utilized as the shaving materials for production of ultrashort-cut fibers. Since the reel 10 is hexagonal in the example shown in Fig. 1, six fiber bundle (Fs1, Fs2, ..., fs6) sections are provided as materials for production of shaving materials to be embedded in the embedding material.

In Fig. 1, 12 is a tension detector which is used for tension control during winding while the tension of the supplied yarn group y is controlled to within the prescribed tension range. By supplying the tension-controlled yarn group y to the winder 1, it is possible to apply the necessary tension for improved alignment when winding up the yarn group y onto the winding width controlling members 11. In the example shown in Fig. 1, the method of unrolling each yarn (y1, y2, y3) from the wound yarns (P1, P2, P3) is a "vertical drawing system". In this type of system, unrolling of the wound yarns (y1, y2, y3) introduces an unrolling twist for each unrolling. In order to prevent such unrolling twists, therefore, a "horizontal drawing system" may be employed wherein the wound yarns (P1, P2, P3) are rotated for unrolling of the yarns (y1, y2, y3).

Also, although they are not shown in the example of Fig. 1, tension compensators 3 (31, 32, 33) commonly employed in preparatory steps such as warping machines for warping of warp to be supplied for weaving, are preferably provided for each yarn (y1, y2, y3) when unrolling and drawing out each yarn (y1, y2, y3) from each wound yarn (P1, P2, P3). However, these tension compensators 3 are provided for each wound yarn (P1, P2, P3), and are generally used to stabilize the unrolling tension in order to avoid significant variation in the unrolling tension during unrolling of the yarns (y1, y2, y3)

from each wound yarn (P1, P2, P3). The tension compensators 3 used may be commercially available ceramic products which have low friction coefficients and abrasion resistance, and will not be explained further here.

According to the invention, as described above, each of the yarns (y1, y2, y3) is unrolled from each wound yarn (P1, P2, P3) via a tension compensator 3 to avoid extreme variation in the unrolling tension. Preferably, the winding is carried out at a predetermined constant tension to improve paralleling of the fiber bundle F wound up on the reel 10. This applies whether the doubling step is detached as a separate step, or whether the doubling step is continuous as shown in Fig. 1. The following explanation, however, relates to a system wherein the doubling step is linked to the step of winding onto the reel 10 by the winder 1.

The winder 1 of the invention is provided with a tension detector 12 which detects the tension of the supplied yarn group y in order to control the winding tension. Winding is performed while controlling the winding speed of the winder 1 so as to maintain a constant tension as detected by the tension detector 12. In this case, a torque motor is used as the driving motor (not shown) for rotation of the reel 10, and may be adjusted for winding at a constant torque. In other words, it is essential according to the invention for the yarn group y to be lap wound onto the reel 10 at a predetermined constant tension, regardless of the winding system or winding mechanism used.

A preferred embodiment of the winder 1 of the invention is a winder having a traverse mechanism 13, wherein during winding of the fiber bundle F on the winding width controlling members 11, the yarn group y supplied to the reel 10 is wound up with traverse movement by a traverse guide (not shown) matching the winding width of the controlling members 11.

This is because winding up the yarn group y on the winding width controlling members 11 with proper alignment in the widthwise direction will result in improved paralleling of the fiber bundle F.

Thus, each fiber bundle (Fs1, Fs2, ..., Fs6) in the fiber bundle F wound on the reel 10, wound up at the six locations corresponding each side of the hexagonal reel, can be maintained in a tightened state by the tension applied during winding, and can thus be wound up in a linear fashion. Since the fiber bundles (Fs1, Fs2, ..., Fs6) at the straight sections are in a very satisfactory paralleled state, those sections, when directly embedded into the embedding material described above, form a suitable shaving material material for obtaining ultrashort-cut fibers.

A quick-drying adhesive which satisfactorily infiltrates into the individual filament groups is impregnated into the fiber bundles (Fe1, Fe2, ..., Fe6) wound at the vertices of the hexagonal frame together with the fiber bundles (Fs1, Fs2, ..., Fs6) which are wound at the straight sections on the reel 10. The adhesive is then hardened to anchor the fiber bundles (Fe1, Fe2, ..., Fe6), as a preferred embodiment of the invention. This is because producing such a state will restrict free movement of the individual filament groups of the fiber bundle F which might shift their relative positions, even when the fiber bundle F moves from a state of tension to a state of relaxation due to cutting of the fiber bundle F, collapsing of the reel 10, etc. The fiber bundle F can therefore be restored to a state of tension to easily restore the original satisfactorily paralleled state.

Incidentally, since the anchored sections of the fiber bundle (Fe1, Fe2, ..., Fe6) are not linearly paralleled, they are unsuitable as shaving materials for shaving to obtain ultrashort-cut fibers. According to the invention, therefore,

it is preferred to adhesively anchor these sections (Fe1, Fe2, ..., Fe6) which cannot be used as shaving materials. However as will be explained below, although it is a preferred embodiment of the invention for the fiber bundles (Fe1, Fe2, ..., Fe6) to be anchored with an adhesive, this is not essential.

The reel 10 of the invention described above was a regular polygonal frame such as the hexagonal frame shown in Fig. 1. However, the reel of the invention is not limited to this example, and may be instead a reel 10' having a frame which is not regular polygonal, as illustrated in Fig. 2. The reel shown in Fig. 2 is provided with winding width controlling members 11' at both ends of a rod-shaped reel 10', and the two winding width controlling members 11' act as loop back members to lap wind the yarn group y' on the winding width controlling members 11', in order to obtain a fiber bundle F' having a prescribed overall size.

In this example, however, the doubled yarn group y is looped back and wound at the winding width controlling members 11'. As a result, the tension variation is greater than with a polygonal reel such as the hexagonal reel 10 of Fig. 1. Therefore, in the winder 1' used in this example, it is necessary to reduce the effect of the large variation in unrolling tension when each yarn of the yarn group y' is unrolled from the wound yarn group P'. It is preferred, therefore, to provide a tension compensator 3' for each wound yarn P' to prevent increase in the range of variation in the unrolling tension. After minimizing the range of variation in the unrolling tension, the rotation of a servomotor 14' is controlled while detecting the winding tension with a tension detector 12'. The yarn group y' doubled with the doubling means 2' is wound above it at the prescribed winding tension by a traverse apparatus 13' on the rod-shaped reel 10'.

The fiber bundle production process and apparatus of the invention as described above can yield a fiber bundle prepared for a prescribed overall size of 10,000 to 10 million dtex, and in a satisfactorily paralleled state. A step of embedding treatment of such a satisfactorily paralleled fiber bundle with an embedding material in order to obtain ultrashort-cut fibers by shaving will now be explained in detail with reference to Figs. 3 to 6.

According to the invention, the embedding treatment with the embedding material may be carried out with the fiber bundle wound on the polygonal reel 10 illustrated in Fig. 1 or the rod-shaped reel 10' illustrated in Fig. 2. Fig. 3 shows a concrete embodiment for a process of embedding a fiber bundle F wound up using the hexagonal winding reel 10 shown in Fig. 1, wherein Fig. 3(a) is a schematic plan view and Fig. 3(b) is a schematic side view.

Fig. 4 is a schematic illustration (plan view) showing a treatment tank 4 for embedding treatment of a fiber bundle F with an embedding material 5. Fig. 5 is a pair of schematic drawings illustrating a step of embedding treatment in which the winding reel 10 with the fiber bundle F wound thereon is immersed in a treatment tank 4 filled with a liquefied embedding agent 5, wherein Fig. 5(a) is a schematic plan view and Fig. 5(b) is a schematic side view. Fig. 6 is a schematic side view showing the state after the liquefied embedding agent 5 has been cooled to solidity and then removed out of the treatment tank 4.

To repeat for emphasis, according to the invention the terms "embedding agent" and "embedding material" are both used, with the term "embedding agent" referred to the liquid state or gaseous state, and the term "embedding material" referring to the solid state. In the examples shown in Figs. 3 to 6, the reel illustrated is a hexagonal one as in Fig. 1, but

there is no limitation whatsoever to this type so long as it satisfies the gist of the invention.

According to the invention, the embedding treatment can be carried out directly using the reel 10 with the fiber bundle F wound thereon. When the reel 10 is demounted from the winder 1 as the first step, it is essential to keep the fiber bundle in a tightened state without deformation, in order to satisfactorily maintain the paralleled state of the fiber bundle F wound on the winding width controlling members 11 as explained above. Thus the mechanism is preferably such that when the lock is released, the reel 10 is freely attachable/detachable from the rotation driving axis. This will allow the reel 10 to be demounted from the winder 1 without directly contacting with the wound fiber bundle F.

When the reel 10 is demounted as described above, the next step employs a treatment tank 4 prepared having a hexagonal shape as shown in Fig. 4, corresponding to the hexagonal reel 10 of this embodiment. The treatment tank 4 is filled with the liquid embedding agent 5 (for example, water, molten paraffin or molten resin). For paraffin or resins which do not melt at ordinary temperature, the treatment tank 4 is equipped with a heating apparatus for heating of the treatment tank 4 to allow melting.

As shown in Fig. 5, the reel 10 with the fiber bundle F wound thereon is immersed in the treatment tank 4 filled with the liquid embedding agent 5 as explained above. The details of this treatment will be explained below, but for removal of the air bubbles in the fiber bundle F, the reel 10 with the fiber bundle F wound thereon may be placed, together with the treatment tank 4, in a vacuum container for vacuum degassing, to accomplish embedding treatment of the vacuum degassed fiber bundle F. After immersing the fiber bundle F in the liquefied embedding agent 5 and completing sufficient impregnation of

the embedding agent 5 between the individual filament groups of the fiber bundle F, it is cooled to solidify the embedding agent 5 and embed the individual filament groups of the fiber bundle F in the solidified embedding material 5.

As the final step, shown in Fig. 6, the straight sections necessary for shaving of the embedded fiber bundle F to obtain ultrashort-cut fibers are cut out with a cutter, to obtain shaving materials. The cutter is used for cutting out of the sections indicated by dotted lines as shown in Fig. 6, for example. Thus, the straight fiber bundle (Fs1, Fs2, ..., Fs6) sections shown in Fig. 1 may be supplied as shaving materials for production of ultrashort-cut fibers.

The embodiment described above accomplishes embedding treatment by removal of the reel 10 or 10' from the winder 1 or 1', using the reel 10 or 10' with the fiber bundle F or F' wound around the winding width controlling members 11 or 11', and this process is preferred according to the invention. However, the invention is not limited to this example, and as mentioned above, the fiber bundle F or F' treated with an adhesive, or clamped, may be cut out from the reel 10 or 10' and subjected to embedding treatment after being cut out from the reel 10 or 10'. This type of embedding treatment will now be explained in detail with reference to Figs. 7 and 8.

Fig. 7 is a schematic illustration (plan view) showing an embodiment of embedding treatment carried out with the fiber bundle F cut out from the reel 10. For this embedding treatment, as shown in Fig. 7, split embedding agent-filled containers 6 are mounted at the straight fiber bundle (Fs1, Fs2, ..., Fs6) sections shown in Fig. 1. The embedding agent-filled containers 6 have split structures, and preferably when the split sections are joined, they are fitted on the straight fiber bundle (Fs1, Fs2, ..., Fs6) sections and clamped via a seal material such as silicone rubber so that the embedding

material in its liquid state does not leak from the ends clamping the straight fiber bundle (Fs1, Fs2, ..., Fs6) sections or from the split sections. Here, the seals may be enhanced by using a liquid or paste-like sealing agent as an auxiliary agent for the seal.

With the embedding agent-filled containers 6 mounted on the straight fiber bundle (Fs1, Fs2, ..., Fs6) sections, the liquid embedding agent 5 is circulated through the embedding agent-filled containers 6 through in ports 6a and out ports 6b. Air bubbles present in the fiber bundle F and the air present in the embedding agent-filled containers 6 are forced out when the embedding agent 5 is filled into the embedding agent-filled containers 6. However, if water is used as the embedding agent 5, its low viscosity will permit its satisfactory infiltration into the fiber bundle F. Next, the embedding agent-filled containers 6 may be cooled in this state to minus temperature for freezing of the internal water, to accomplish successful embedding of the fiber bundle F with an embedding material composed of ice.

As already mentioned above, after the fiber bundle (Fe1, Fe2, ..., Fe6) sections wound at each vertex of the hexagonal reel 10 as shown in Fig. 1 have been anchored with an adhesive to completely restrict the freedom of movement of the individual filaments at those sections, the sections may be cut and removed from the reel. In this case, the reel 10 may have a freely collapsible structure, whereby the reel 10 alone is shrunken and demounted without cutting the fiber bundle F, and the fiber bundle F alone may be subsequently removed out. As a concrete example of such a collapsible structure, the six rod-shaped frames extending out in a radial fashion which support the winding width controlling members 11 shown in Fig. 1 may have a telescopic structure or a freely foldable structure employing hinges, for expansion and collapse.

If the fiber bundle F can be easily removed from the reel 10 in this manner, it will be possible to restore the fiber bundle F to the original satisfactory paralleled state by holding both ends of the adhesive-treated sections and applying the prescribed tension. In this case, care must be taken to avoid major deformation of the removed fiber bundle F when the fiber bundle F is removed from the reel 10. This is because major deformation of the removed fiber bundle F can cause deformation of the individual filament groups of the fiber bundle F at sections other than the sections anchored with the adhesive, causing them to shift their relative positions. With application of low tension, therefore, friction between the filaments can become significant, producing a condition in which it will be difficult to restore the individual filaments to the original positions.

Thus, as shown in Fig. 8, a stretching jig 7 is built to apply the prescribed tension in the directions of the arrows in order to avoid major deformation of the fiber bundle F during demounting of the fiber bundle F, and the jig 7 is fitted at the straight fiber bundle (Fe1, Fe2, ..., Fe6) sections which are wound on the reel 10. A modification wherein the fiber bundle F is cut out from the outer ends of the jig 7 is preferred, taking care to avoid major deformation of the fiber bundles (Fe1, Fe2, ..., Fe6) at these sections. This will allow each jig to be supplied for embedding treatment instead of the reel 10 shown in Figs. 3 to 6, and thereby further facilitate the embedding treatment shown in Figs. 3 to 6.

Each of the strands of the individual filament groups of the fiber bundle F are generally very thin and flexible. Consequently, since they readily undergo elastic deformation in the direction of the cutting force and slip away from the blade, as mentioned above, it is normally not easy to produce

ultrashort-cut fibers with fiber lengths of 0.1 mm or smaller. According to the invention, however, the individual filament groups of the fiber bundle F are set with the embedding material and their freedom of movement is therefore restricted, to prevent them from easily moving. The fiber bundle F set by the embedding material is then cut into thin slices using a shaving blade. In order to achieve this object, the embedding agent must have a property allowing it to be converted to a low viscosity fluid state, whereby the fiber bundle can be easily surrounded to allow the agent to envelop and infiltrate into the interstice of the fiber bundle from the periphery.

As it is a feature of the invention that the liquid embedding material infiltrates throughout the interior of the fiber bundle to restrict freedom of movement of the long individual filaments, this embodiment will now be explained in detail with reference to the accompanying drawings.

Fig. 9 is a schematic partial front cross-sectional view of an embodiment of embedding treatment of fiber bundles by the process for production of ultrashort-cut fibers according to the invention. Fig. 10 is a pair of cross-sectional plan views along line A-A of Fig. 9. Fig. 10(a) shows an embodiment of small fiber bundles with flat rectangular cross-sections (cross-section in the direction orthogonal to the direction of fiber lengths), and Fig. 10(b) shows an embodiment of small fiber bundles with non-flat circular cross-sections.

As the reference notations in these drawings, F represents small fiber bundles, 12 is the embedding agent (embedding material), 13 is the container, 13a is an in port for liquid-phase converted embedding material, and 14 is a clamping member. As already described at length above, the small fiber bundles F are prepared by aligning yarn groups y and bundling them in a straight paralleled state, and then

cutting both ends to create equal lengths of the small fiber bundles F.

Next, the group of small fiber bundles F are anchored by the clamping member 14 which clamps and anchors both ends of each of the small fiber bundles F prepared in the manner described above. Here, the group of small fiber bundles F anchored by being clamped by the clamping member 14 must be situated with an appropriate spacing W between adjacent small fiber bundles F so that the embedding agent 12 which has undergone phase conversion to liquid can surround the small fiber bundles F and penetrate to their interiors. The optimum value for the spacing W may be determined by experimentation, since the ease of infiltration between the small fiber bundles F will differ depending on the nature of the embedding agent 13 used. For example, when water which has undergone phase conversion to a liquid state is used, the spacing is preferably 0.5 mm or greater, and more preferably 2 mm or greater.

According to the invention, the freedom of movement of the long individual filament groups of the small fiber bundles F is restricted by being anchored with the embedding material 12. It is therefore essential for the embedding agent 12 which has undergone phase conversion to a liquid state to be able to easily reach the deepest center sections of the small fiber bundles F after the agent has been introduced between the small fiber bundles F so as to surround the periphery of the group of small fiber bundles F. This introduces the concept of the "maximum required infiltration distance" necessary for the embedding agent 12 which has undergone phase conversion to a liquid state to infiltrate to the deepest centers of the small fiber bundles F, in order to realize the situation described above.

The "maximum required infiltration distance" according to

the invention will now be explained with reference to Fig. 11. In Fig. 11, (a) shows an example of a small fiber bundle F having a flat rectangular lateral cross-section, and (b) shows an example of a small fiber bundle F having a flat oblong lateral cross-section. L represents the center line.

In these two embodiments, the embedding agent 12 which has undergone phase conversion to a liquid state can easily surround the periphery of the small fiber bundles F since the small fiber bundles F are aligned without mutual contact, at a prescribed spacing W. The problem is how to allow the embedding agent 12 thus surrounding the periphery of the small fiber bundles F to easily reach the deepest interiors of the small fiber bundles F. In the embodiment shown in Fig. 11(a), the "maximum required infiltration distance dmax" is always the same value along the lengthwise direction of the lateral cross-section as shown, while in the case of Fig. 11(b), the maximum required infiltration distance dmax is at the position of maximum thickness of the small fiber bundle F at the lateral cross-section, as shown.

The term "flat" as used according to the present invention means that the ratio of the maximum length in the flat extended direction ("horizontal length") and the minimum length in the direction orthogonal thereto ("vertical length") ("vertical/horizontal ratio = vertical length/horizontal length") is no greater than 1/3, as seen from the cross-section of the fiber bundle F (cross-section in the direction orthogonal to the lengthwise direction of the individual filaments of the fiber bundle). For example, as a concrete explanation of the "vertical/horizontal ratio" with reference to Fig. 11(a) and Fig. 11(b), the "vertical/horizontal ratio" is the "short side length/long side length" for the fiber bundle F having the rectangular cross-section in Fig. 11(a), while the "vertical/horizontal ratio" is the "short diameter

length/long diameter length" for the fiber bundle having the oblong cross-section in Fig. 11(b).

Since it is essential for the embedding agent 12 to be able to easily penetrate into the deepest center sections of the small fiber bundle F, the maximum required infiltration distance dmax must not exceed 5 mm. This is because when thin individual filament groups of 0.001-10 dtex are bundled, the interstices between the individual filament groups are extremely small. The embedding agent 12 is therefore unable to adequately infiltrate to the interior. As a result, since an increased small fiber bundle F thickness will not allow the embedding agent 12 to infiltrate to the deepest sections of the small fiber bundles F, the maximum required infiltration distance dmax must not exceed 5 mm.

If the small fiber bundles F are in a densely arranged state, it becomes difficult for the embedding agent 12 to infiltrate to the deepest sections of each small fiber bundle F. There is no particular restriction on the arrangement so long as the small fiber bundles F are arranged at the prescribed spacing without contact. As preferred arrangements of the small fiber bundles F when the lateral cross-sections of the small fiber bundles F shown in Fig. 10 are circular, there may be mentioned the lattice arrangement shown in the drawing, or any desired arrangement such as circular, zig-zag or the like, as appropriately selected within a range which satisfies the gist of the invention.

Incidentally, when air bubbles are included in the fiber bundles F embedded in the manner described above, non-bound individual filament groups may appear, depending on the embedding agent (embedding material), to result in miscutting. According to the invention, therefore, it is necessary to prevent inclusion of air bubbles in the embedded fiber bundles F. A method of preventing residual air bubbles in the

embedding agent (embedding material) will now be explained, for a case of using water (ice) as the embedding agent (embedding material).

As embedding agents 12 which may be suitably used, there are preferred agents with excellent permeability and dispersability, to facilitate infiltration between the individual filament groups. Using a surfactant in admixture with the embedding agent 12 which has undergone phase conversion to a liquid state can facilitate impregnation of the embedding agent to the interior of the small fiber bundles F. Water in admixture with a surfactant may be mentioned as an example of such an embedding agent.

Incidentally, the small fiber bundles F to be embedded have minute spaces in their interiors as mentioned above, and naturally, the spaces contain air in their ordinary state. Consequently, if the air remains in that state in the groups of small fiber bundles F, the air between the individual filament groups will constitute a hindrance when the fiber bundle composed of the bundled groups of small fiber bundles F is immersed in the embedding agent 12, thereby preventing thorough infiltration of the embedding agent 12 into the small fiber bundles F.

Consequently, for embedding treatment with the embedding agent 12, it is preferred to first remove the air in the interior of the small fiber bundles F, and subject the container for embedding treatment to vacuum aspiration to force out the air in the container. Carrying out the embedding treatment after removing the air in the interiors of the individual filament groups of the fiber bundles allows the embedding agent to be more satisfactorily impregnated into the fiber bundle interiors. This will be explained in greater detail with reference to Fig. 12, as a schematic illustration of producing fiber bundles according to the invention. In Fig.

12, 13 represents containers for embedding treatment similar to the one shown in Fig. 9, 15 represents a degassing tank, 16 represents a vacuum aspirator and 17 represents a vacuum tube.

In the degassing apparatus having this construction, the group of small fiber bundles F are placed in the container 13, as shown in Fig. 9 and Fig. 10. Also, after the group of containers 13 has been placed in the degassing tank 15 and the degassing tank 15 sealed for airtightness, the air in the degassing tank 15 is aspirated by the vacuum aspirator 16 through the vacuum tube 17. Once a vacuum state has been produced, the embedding agent is injected into the container 13 through the in port 13a of the container 13 using a volumetric pump, and the prescribed amount of embedding agent is filled into each container 13 for adequate infiltration of the embedding agent into the fiber bundle F.

The vacuum state may be a degree of vacuum which can be ordinarily achieved with the vacuum aspirator 16, and there are no necessary restrictions on the degree of vacuum. A preferred degree of vacuum is, for example, about 10-300 Torr. A vacuum of below 10 Torr is not preferred as it will result in extreme vaporization if water is used as the embedding agent, thus requiring use of excess water in the amount of vaporization. A vacuum of above 300 Torr is also not preferred because it will not allow adequate removal of the air bubbles in the fiber bundle interiors.

According to the invention, the embedding agent 12 is still in a liquid state after completion of degassing, and therefore the individual filament groups must be anchored with the embedding agent by its phase change to a solid state. The completely degassed degassing tank 15 is opened to the atmosphere to allow cooling of the group of containers 13 in the degassing tank 15, thereby solidifying the embedding agent 12 to obtain a solid embedding material 2.

In the degassing step described above, the group of containers 13 containing the fiber bundles F is placed in the degassing tank 15 and then the air in the degassing tank 15 is vacuum aspirated to force out the air inside the group of containers 13, before injecting the embedding agent into the group of containers 13. As an alternative to this method, however, the embedding agent 12 may be filled into the group of containers 13 first, and the group of containers 13 filled with the embedding agent 12 placed in the degassing tank 15 for vacuum aspiration. When it is necessary to remove the air bubbles more thoroughly, the degassing tank 15 may be cooled with the degassing tank 15 in an evacuated state to solidify the embedding agent 12. Conversely, as another preferred mode opposite to vacuum aspiration of the degassing tank 15, it may be pressurized to a high pressure for pressurized degassing of the air bubbles in the embedding agent 12. As yet another preferred mode, the method described above may be used in combination with admixture of the embedding agent 12 with a surfactant having affinity with fibers and a defoaming property.

The common example of a surfactant used in clothing detergent may serve for explanation of the surfactant mixed with the embedding agent 12. Such a surfactant surrounds oil and dirt components adhering to clothing fibers, penetrating the gaps between the fibers and the oil and dirt components, and eventually eliminating the oil and dirt from the fibers. Therefore, using the embedding agent 12 in admixture with a surfactant can result in satisfactory penetration of the embedding agent 12 into the spaces between the individual filament groups. Thus, as the embedding agent 12 penetrates into the minute spaces between the individual filament groups and wets the individual filament groups, trace amounts of air may still reside between the individual filament groups, but

the action of the surfactant will allow the embedding agent to surround the trace amounts of air and isolate the residual trace amounts of air for their removal. In addition, the embedding agent will have greater affinity with the individual filament groups to allow more satisfactory embedding treatment.

Surfactants with such a function include nonionic surfactants such as polyalkyleneglycol esters and ethers, anionic surfactants such as alkali metal salts of fatty acids, alkyl phosphates, sulfonates and sulfates, cationic surfactants such as quaternary ammonium salts and amphoteric surfactants such as alkali metal salts of aminocarboxylic acids, or alkylbetaines or the like.

Before the embedding treatment of the invention, the embedding agent 12 is preferably boiled to drive out the gas components dissolved in the embedding agent 12. This will prevent bubbling of the air dissolved in the embedding agent 12, for any of various reasons, during the embedding treatment. Generation of bubbles in the fiber bundles F can therefore be inhibited, to reinforce the binding force of the solidified embedding material on the individual filament groups.

In order to induce phase conversion of the embedding agent 12 to a solid state to restore it to an embedding agent material, the embedding agent 12 is preferably solidified by gradual phase conversion over a sufficient period of time, and for example, a long period of time from 8 to 48 hours, in order to inhibit generation of air bubbles in the fiber bundles F during the procedure. A period of less than 8 hours is not preferred because the embedding agent 12 will solidify before the air bubbles in the fiber bundles F escape, and air bubbles will therefore be left in the fiber bundles F. On the other hand, a period of greater than 48 hours is not preferred from the standpoint of production efficiency, since production of the fiber bundles F will be excessively lengthened. The

means for adjusting the time to solidification of the embedding agent 12 may involve appropriate selection of the method of adjusting the cooling temperature and the method of automatically reducing the cooling temperature in a stepwise manner.

Certain conditions must be kept in mind for freezing treatment when the fiber bundles F are frozen with water. These conditions will now be explained in detail with reference to Fig. 13 which shows an embodiment of a freezing treatment apparatus for freezing treatment. Fig. 13 is a simplified configuration diagram showing the construction of the apparatus for schematic illustration of the freezing treatment method and freezing treatment apparatus of the invention.

In Fig. 13, the freezing treatment apparatus of the invention comprises a refrigerating device 21, a freezing vessel 22, an fixture 23, a vacuum chamber 24, a gas-liquid separator 25, an exhauster 26, a heating device 27, a microvibrator 28 and a control apparatus 29. The section enclosed by the two-dot chain line in Fig. 13 is the refrigerating device 21 composed of, for example, a freezer or the like, and it is provided to freeze the water (embedding agent) infiltrated in the fiber bundles F standing in the freezing vessel 22, whereby the fiber bundles F are subjected to freezing treatment (embedding treatment) by the ice (embedding material). The refrigerating device 21 is not limited to a freezer, and may be a system which immerses the freezing vessel 22 in a refrigerant bath.

Here, the fiber bundles F in a parallel state have both ends anchored by the fixture 23, and the ends are cut outside the fixture 23. The fiber bundles F are allowed to stand suspended in the freezing vessel 22 filled with the separately degassed water while anchored by the fixture 23.

The vacuum chamber 24, also serving as the cover member of the freezing vessel 22, is provided at the top of the freezing vessel 22. The heating device 27 is provided around the periphery of the vacuum chamber 24 to heat the vacuum chamber 24 during freezing treatment. The heating device 27 is provided to delay freezing from the water surface formed by the water filling the freezing vessel 22. Specifically, the density of the water supplied to the freezing treatment is greatest at 4°C, and therefore the heating device 27 is used to prevent the freezing from starting at the water surface formed at the cover member, with water at 0°C pressing against the cover member of the freezing vessel 22 above it.

The reason for this is that if the water surface formed in the cover member of the freezing vessel 22 freezes, the air dissolved in the lower water will result in an increased concentration of dissolved air in the water as ice is produced on the water surface, eventually producing bubbles in the water. In addition, the bubbled air will be kept from escaping and will be enclosed in the interior by the ice already formed above. However, heating of the cover member of the freezing vessel 22 by the heating device 27 prevents freezing of the water surface formed at the cover member. This allows the bubbled air to easily escape from the unfrozen surface. Bubbling of the air dissolved in the water when the water in the freezing vessel 22 freezes occurs because water has an air solubility of 2.78×10^{-2} at 0°C in air while the solubility of air in frozen ice is zero, such that the air dissolved in the water will reside in the ice as a gas as the water freezes.

The aforementioned cover member also serves as the vacuum chamber 24, and the air bubbled from the vacuum chamber 24 is discharged by the exhauster 26. Thus, once the total amount of water in the freezing vessel 22 has finished freezing,

bubbled air no longer remains in the ice. Because of the important role performed by the heating device 27, it is preferably controlled so as to set the desired heating temperature and heating time. A concrete means for achieving this is to provide a control apparatus 29 which controls the heating temperature.

The heating temperature and heating time for the heating device 27 is preferably set based on experimentation. For example, there is no reason to operate the heating device 27 after the total amount of water in the freezing vessel 22 has been completely frozen by the refrigerating device 21. On the contrary, this would be disadvantageous from the standpoint of running cost since the refrigerating device 21 must then be used in a continuous manner. In the production process for ultrashort-cut fibers, both ends of the freeze treated fiber bundle are cut off by a cutter. Consequently, there is little point in continuously carrying out the refrigeration procedure until the total amount of water filling the freezing vessel 22 is completely frozen. Therefore, if the freezing treatment of the fiber bundles F is already completed up to the portion cut off by the cutter, there is no further need to continue freezing of the fiber bundles F.

The gas-liquid separator 25 used to separate the gas and liquid is mounted after the vacuum chamber 24. The air present in the vacuum chamber 24 above the water surface is preferably evacuated under slightly negative pressure of 30-650 Torr by the exhauster 26 comprising a vacuum pump and air exhaust ventilator, through the exhaust pipe. Here, the degree of vacuum in the vacuum chamber 24 is preferably slightly negative pressure because an excessively large degree of vacuum will accelerate vaporization of the water filling the freezing vessel 22 more than is necessary, while also running up equipment and operating costs due to the

construction required to achieve such a vacuum, and it is therefore not advisable. On the other hand, the degree of vacuum is preferably not too low, because this will reduce the effect of forcing out bubbled air in the water during the freezing treatment.

Thus, moisture will be removed from the air including the water droplets which is discharged by aspiration from the vacuum chamber 24, so that only the air will be discharged from the exhaust tube through the exhauster 26 out of the system. Consequently, air bubbles produced in the degassed water standing in the fiber bundle F freezing vessel 22 filled with the separately degassed water, or air held in the fiber bundles F when the fiber bundles F are standing in the freezing vessel 22, are continuously or intermittently aspirated and discharged during the freezing treatment.

In the apparatus described above, aspirated discharge can be efficiently carried out in a continuous manner during freezing treatment (embedding treatment), therefore allowing the bubbled air to also be satisfactorily discharged during the freezing treatment. However, this procedure is preferably combined with microvibration of the freezing vessel 22 in order to actively bubble the air dissolved in the water in the freezing vessel 22, leading to fusion and growth of the bubbles to increase their buoyancy, and aiding their escape from the water surface held in an unfrozen state by heating. Also, microvibration of the fiber bundles F and water can separate the air attached to the fiber bundles F from the fiber bundle surfaces, and is very effective for this purpose. "Microvibration" according to the invention also includes "ultrasonic vibration" whereby vibration is produced by ultrasonic waves.

In order to generate such microvibration, an easily attachable/detachable microvibrator 28 is attached to the

freezing vessel 22 at any desired position either at the side or bottom of the freezing vessel 22, whereby the microvibrator 28 supplies microvibration to the entire freezing vessel 22. The microvibrator 28 used may be a known microvibrator such as an electromechanical vibrator, acoustic vibrator or the like. The vibration frequency or amplitude produced by the microvibrator must be varied depending on the conditions such as the dimensions and shape of the freezing vessel 22 or the overall size of the fiber bundles F, and therefore it is preferably designed to allow variation to the prescribed value to match the conditions.

The fiber bundles F are subjected to freezing treatment with the microvibrator 28 attached to the freezing vessel 22 in the manner explained above. However, since the density of water at 0°C is 0.9988 g/cm^3 while the density of ice at 0°C is 0.917 g/cm^3, it is therefore necessary to consider the expansion in volume of approximately 10% when the water is converted to ice. For this reason, freezing of water in a freezing vessel 22 having a fixed volume can result in defects such as cracks or fractures due to internal stress caused by the expanded volume of the ice. If defects such as cracks or fractures occur in the frozen ice, problems may result to hinder satisfactory production of ultrashort-cut fibers with fiber lengths of 0.1 mm or smaller by thin shaving of the edges of the frozen fiber bundles F.

Incidentally, since the freezing vessel 22 is situated inside the refrigerating device 21, the internal water will begin to freeze from the walls of the freezing vessel 22, but as mentioned above, heating of the cover member by the heating device 27 causes this portion of water to be frozen last. Consequently, the ice growth occurs gradually from the bottom wall of the freezing vessel 22 while microvibration is being applied to the unfrozen water, and therefore freezing of the

water in the freezing vessel 22 proceeds from the bottom and sides of the freezing vessel 22 toward the top where the cover member is situated.

In contrast, when the apparatus of the invention is not used, freezing begins from the top including the water surface and from the walls of the freezing vessel 22 and surrounds the unfrozen water, with freezing gradually proceeding toward the interior. As a result, when the unfrozen water enclosed in the interior begins to freeze, defects such as cracks and fractures are generated due to the internal stress of volume expansion of the ice. According to the invention, however, the unfrozen water can move freely upward during the freezing for the reason described above. This reduces the internal stress due to volume expansion as the water undergoes phase conversion to ice, thereby preventing generation of defects such as cracks and fractures.

Naturally, this freezing treatment of water in the freezing vessel 22 is highly effective even from the viewpoint of eliminating air bubbles in the ice serving as the embedding material. This is because the air bubbles in the ice serving as the embedding material can be eliminated by final freezing of the water containing bubbled air, while the air dissolved in the water to be frozen is bubbled in the unfrozen water. Consequently, the dissolved gas around the fiber bundles F is not frozen in the form of bubbles, making it possible to shave the bundles with the shaving blade and thus mass produce ultrashort-cut fibers with fiber lengths of for example, 0.1 mm and smaller at a high yield without miscutting.

As explained above, a preferred embodiment according to the invention is to apply microvibrations to the water in the freezing vessel 22 with a constant temperature gradient between the top and bottom of the freezing vessel 22, or to carry out the freezing while stirring at 50 rpm. For example,

the bottom and sides of the freezing vessel 22 are preferably cooled to a temperature of -1°C to -20°C, while the top (cover member section) of the freezing vessel 22 is preferably heated to a temperature of 0-5°C. This will keep the bottom and sides of the freezing vessel 22 at the prescribed low temperature while maintaining the prescribed higher temperature at the top, thus causing freezing of the water from the bottom toward the top of the freezing vessel 22, so that the bubbled air will not be trapped in the freezing vessel 22.

If the water in the freezing vessel 22 is subjected to vibration by a microvibrator 28 or the like, the unfrozen water will constantly be in motion. Air bubbles which might be trapped in the initial frozen water are therefore repelled and return to the unfrozen water. Eventually, the fiber bundles F become embedded by clear ice with no air bubbles. As the temperature gradient, the temperature for cooling of the bottom of the freezing vessel 22 is -1°C to -20°C (preferably -2°C to -5°C) because at a higher temperature the temperature gradient will be too gentle, preventing freezing from the bottom of the freezing vessel 22. Also, the water temperature for heating of the vacuum chamber 24 also serving as the cover member is 0-5°C (preferably 0-2°C) because keeping it at a lower temperature will cause freezing to start from the top of the freezing vessel 22, thereby trapping the air bubbles and preventing them from escaping to the top.

The embedding material (embedding agent) used for the invention may be, instead of ice (water) as explained above, a material which when heated undergoes a phase change from solid to gas (gasification), such as dry ice, or a material which upon heating undergoes a phase change from solid to liquid (liquefaction), as does ice. This is because heating the embedding material to produce a gas or liquid which is

amorphous and in a low viscosity fluid state will create free deformation to allow surrounding of the fiber bundles F, while the low viscosity will allow easy infiltration between the individual filament groups of the fiber bundles F. If cooling is then carried out below the temperature at which the embedding agent solidifies, the individual filament groups of the fiber bundles F will solidify in a state of integration with the embedding material. This will prevent the individual filaments from easily slipping from the shaving blade when the shaving blade acts on the individual filaments, thereby allowing a greater force to be applied.

As explained above, it is a major feature of the invention that the fiber bundles F are embedded with the embedding material first. Paraffin may also be suitably used as the embedding material in addition to the dry ice or ice mentioned above, while a thermoplastic resin having a much lower molecular weight than the fibers to be embedded may also be used. Such low molecular weight thermoplastic resins are not particularly restricted so long as they have low melting points and melt viscosities, and can be easily separated from the ultrashort-cut fibers which are produced; for example, there may be used commonly known low molecular weight thermoplastic resins such as low polymerized polyesters, low polymerized polystyrene, low polymerized polyethylene and the like, selected as appropriate for use depending on the conditions.

It is another major feature of the invention that the ultrashort-cut fibers and embedding material are easily and thoroughly separated after shaving in the ultrashort-cut fiber production process. In order to achieve easy and through separation, therefore, it is preferred to use dry ice or ice as the embedding material, and as mentioned above, ice is particularly preferred. Using ice as the embedding material

is particularly preferred because, as mentioned above, a simple apparatus can be used for easy freezing of the fiber bundles.

When a material other than dry ice or ice, such as paraffin or a thermoplastic resin, is used as the embedding material, it is possible to employ a method wherein, for example, the embedding material is melted by heating and then the melted embedding agent is dissolved with an organic solvent or the like and removed, after which a drying step is performed to effect separation and removal of the organic solvent from the ultrashort-cut fibers. Thus, the production process of the invention can very satisfactorily prevent contamination of other materials into produced ultrashort-cut fibers as occurs in the prior art.

If dry ice is used as the embedding material, the embedding material can be easily and conveniently separated from the ultrashort-cut fibers at ordinary operating temperature (for example, room temperature kept at 20°C), in order to accomplish shaving under conditions which do not result in gasification of the dry ice to produce carbon dioxide gas.

When ice is used as the embedding material, it may be heated at a temperature above 0°C and then subjected to a drying step for easy and convenient separation of the embedding material from the ultrashort-cut fibers. According to the invention, therefore, either heat drying or room temperature drying may be employed when using ice as the embedding material.

However, heat drying or room temperature drying can result in significant dimensional change or quality deterioration, especially in the case of a high drying temperature or in the case of ultrashort-cut fibers produced from conjugated fibers comprising two different attached

thermoplastic resins. Particular care must be taken when drying optical interference fibers such as described in Japanese Unexamined Patent Publication HEI No. 11-241223. This is because such fibers are controlled in such a manner that the thicknesses of the mutually attached polymer layers are on the micron order, matching the wavelength of incident light rays, so that incident light will interfere with the attached polymers to display a clear shade. In such cases, therefore, it is preferred to using a freeze drying method which allows removal of water while in a frozen state. Thus, for such conjugated fibers, the means of drying removal of the residual water adhered to the shaved ultrashort-cut fibers may be heat drying or room temperature drying as explained above, but freeze drying is preferred.

For the purpose of preventing such dimensional change or quality deterioration, freeze drying which allows drying to be accomplished at low temperature may be used for the invention. Freeze-drying is a drying method whereby moisture is removed by sublimation as water vapor from a state of ice adhered to the surface of the ultrashort-cut fibers passing through a state of water, and hence there is absolutely no need to heat the ultrashort-cut fibers and a low temperature can be maintained during the freeze drying. This will allow drying to be performed without the problems described above, and therefore when water (ice) is used as the embedding agent (embedding material), freeze drying is very convenient for drying of the water.

When the conditions suitable for freeze drying are examined, a larger surface area of the starting material supplied for freeze drying will allow more efficient sublimation of the water vapor, and is of course preferred. In this regard, since the ultrashort-cut fiber production process of the invention thinly shaves the edges of the frozen

fiber bundles with a shaving blade and fresh shaving surfaces therefore appear one after another, the surface area is very large during production of the ultrashort-cut fibers. However, if shaved aggregates of the ultrashort-cut fibers in a state suitable for freeze drying are left in an aggregated state without some alteration, the freshly produced shaving surfaces will overlap each other, thereby reducing the surface area despite the originally produced large surface areas.

The large surface area newly produced by shaving may therefore be used to maximal advantage. According to the invention, then, it is preferred for the accumulated aggregates of the produced ultrashort-cut fibers to form with air intervening between the thin frozen ultrashort-cut fibers. This will allow the aggregates composed of the shaved frozen ultrashort-cut fibers to gradually accumulate in the form of flakes, as with "shaved ice". Porous aggregates will therefore be obtained, having air-intervening spaces between the aggregates composed of mixtures of ultrashort-cut fibers and ice. If insulated at a temperature at which the ice does not melt (a temperature below the melting point of ice), the porous state will be maintained. A larger dry surface area will result if such a porous starting material is supplied for the freeze drying, thus offering the advantage of a faster drying speed.

When carrying out this type of freeze drying, it is essential for the embedding ice to be insulated during the shaving step so that it does not return to water. For this reason, therefore, the frozen ultrashort-cut fibers are preferably not aggregated under conditions in which the ice adhering to the obtained ultrashort-cut fibers will melt. If they are kept at a temperature at which ice melts to water, it will be necessary to refreeze the melted water because of the need for drying by a freeze drying method, thus resulting in a

waste of energy. In addition, the freezing will occur with the peripheries of the ultrashort-cut fibers embedded in the water. As a result, it will not be possible to create the aforementioned porous state, thus rendering it difficult to increase the drying speed and consequently requiring a greater length of time to remove the moisture by freeze drying.

For the reasons explained above, it is a preferred embodiment of the invention that in the step of aggregating the shaved frozen ultrashort-cut fibers, air cooled to below freezing is blown in to allow a soft landing of the frozen ultrashort-cut fibers, thereby forming bridges between the shaved frozen ultrashort-cut fibers for aggregation. It will, of course, be necessary to adjust the aggregating thickness of the aggregates of the frozen ultrashort-cut fibers, so that the bridges formed are not destroyed under the weight of the aggregated frozen ultrashort-cut fibers themselves. For this purpose it is preferred to use a method wherein the housing means of the frozen ultrashort-cut fibers is traversely moved to produce a roughly consistent aggregating thickness of the shaved frozen ultrashort-cut fibers. Also, from the standpoint of simplifying and streamlining the drying step it is preferred to supply the frozen ultrashort-cut fibers for freeze drying while they are still housed in the housing means. In this case, a minute opening is preferably formed on the contact surface where the housing means contacts with the shaved frozen ultrashort-cut fibers to allow sublimation of the ice as water vapor.

The present invention is characterized by producing ultrashort-cut fibers, not by cutting the fiber bundles F, but by thinly shaving a shaving material composed of the embedded fiber bundles. An embodiment of a shaving apparatus for shaving of ultrashort-cut fibers from an embedded fiber bundle will now be explained with reference to the accompanying

drawings.

Fig. 14 is a simplified schematic configuration diagram showing an apparatus for production of ultrashort-cut fibers according to the invention, wherein 31 is a shaving material (embedded fiber bundles to be shaved), 32 is holding means, 33 is a blade stand, 34 is a shaving blade, 35 is contact pressure applying means, 36 is driving means, 37 is protrusion length adjusting means (not shown in Fig. 14), 38 is ultrashort-cut fiber collecting means and 39 is a mounting frame. The reference letter A represents the contact plane of the blade stand 33 which presses against the shaving edge of the shaving material 31 with a prescribed contact pressure, and since the contact plane A is the shaving base, it must be formed to have sufficient smoothness and flatness. The insulating means and/or cooling means of the holding means 32 are not shown in Fig. 13, but these will explained below. The ultrashort-cut fiber collecting means collects the shaved ultrashort-cut fibers, and for example, it may be a collecting bag or cylindrical container, which is provided surrounding the perimeter of the rotating blade stand 33.

Here, the contact pressure applying means 35 performs the role of pressing the shaving material against the contact plane A of the blade stand 33 with a prescribed force, and as shown in this drawing, it comprises a contact pressure generator 35a, a connecting rod member 35b, a contact pressure transmitting member 35c to the shaving material and an anchoring member 35d, and it is positioned and anchored on the mounting frame 39 (39c) via the anchoring member 35d. An example of the contact pressure applying means 35 is a fluid pressure working cylinder as shown, which works by fluid pressure such as compressed air pressure or oil pressure. However, the invention is not necessarily limited to the embodiment shown in Fig. 14, and any apparatus which allows

the prescribed contact pressure to be applied to the contact plane A of the blade stand 33 with the shaving material 31 may be suitably used. For example, an apparatus which grips and transports the shaving material 31 with a pair of belts or rolls may be used as a well-known transport apparatus allowing continuous or intermittent feeding.

In the example shown in Fig. 14, the driving means 36 comprises rotary driving means which drives rotation of the blade stand 33, and it includes a driving apparatus 36a such as a hydraulic motor or electric motor as the motive power source, a driving end motive power transmitting member 36b, a motive power propagating member 36c, a passive end motive power transmitting member 36d, a rotary driving axis 36e, a bushing 36f and an anchoring member 36g for the bushing 36f. The driving apparatus 36a and the anchoring member 36f are each positioned and anchored on the mounting frame 39b. The passive end motive power transmitting member 36d is attached to one end of the rotary driving axis 36e while the blade stand 33 is attached at the other end thereof, and pivots in a freely rotatable manner at its center by the bushing 36f.

Thus, when the motive power is transmitted as rotating force from the driving apparatus to the rotary driving axis 36e via the driving end motive power transmitting member 36b, motive power propagating member 36c and passive end motive power transmitting member 36d, the blade stand 33 attached to the other end of the rotary driving axis 36e is driven to rotate. As specific examples of the motive power transmitting members 36b and 36d there may be mentioned a toothed pulley, V-belt pulley, gear or the like, and as specific examples of the motive power propagating member 36c there may be mentioned a toothed belt (timing belt), V-belt, chain, intermediate gear or the like.

One or more shaving blades 34 (shown in this drawing as

shaving blades 34a and 34b) whereby the shaving material 31 is shaved to obtain ultrashort-cut fibers are provided on the blade stand 33 in a radial fashion from the center of rotation toward the direction of the radius, so that when the shaving blade 34 is driven to rotate with the blade stand 33, the shaving material 31 contacting with the blade stand 33 is shaved by the shaving blade 34. Here, the rotating speed of the blade stand 33 is preferably freely variable to match the nature of the shaving material 31, and for example, it may be freely adjustable to 0.05-1500 rpm. The rotation speed variation may be accomplished, for example, by controlling the frequency with an inverter, with the driving apparatus 36a as an alternating current motor such as an induction motor or synchronous motor, as is well known, by controlling the supplied pulse number, with the driving apparatus 36a as a pulse motor, or by providing a driver apparatus whereby the frequency is controlled by chopping a direct current, with the driving apparatus 36a as a direct current motor.

The embodiment described in detail above relates to an apparatus whereby the shaving blade 34 is rotated and the shaving material 31 is contacted with the shaving blade 34 to obtain ultrashort-cut fibers, but as an opposite mode, the shaving blade 34 may be anchored and the shaving material rotated and contacted with the shaving blade 34 to shave ultrashort-cut fibers. Also, the shaving blade 34 or shaving material 31 may be moved in a back-and-forth linear fashion instead of rotational motion of the shaving blade 34 or shaving material 31. The essential aspect is that the shaving blade 34 and the shaving material 31 containing the fiber bundle 31a are in relative motion in the shaving direction, whereby the shaving edge of the fiber bundle 31a is thinly shaved.

It is a principal feature of the invention that the

shaving material 31 is shaved to produce ultrashort-cut fibers. This "shaving embodiment" will now be explained in detail with reference to Fig. 15.

Fig. 15 is a magnified front cross-sectional view of the essential part (shaving section) of Fig. 14, and in Fig. 15, the shaving material 31 consists of a fiber bundle 31a embedded in an embedding material 31b as already explained above. The fiber bundle 31a is composed of numerous paralleled individual filament groups, and the overall size of the fiber bundle 31a is between 10,000 and 10 million dtex. The total length of the fiber bundle 31a used here does not necessarily have to be limited, but in consideration of workability and productivity, as well as ease of embedding, it is preferably between 5 and 1000 mm. In the example of Fig. 15 there is shown a mode wherein the fiber bundle 31a cut to the prescribed length is embedded in an embedding material 31b in a separate step from the shaving step and then shaved by batch processing, but the shaving may also be carried out continuously, whereby the fiber bundle 31a composed of continuous individual filament groups is continuously embedded in the embedding material 31b.

Although the embedding material 31b in the interior of the fiber bundle 31a is not shown in Fig. 15, it should be noted that the embedding material 31b is naturally present, though in a small amount, in the interior of the fiber bundle 31a as already explained with the details of the embedding treatment. Particularly as the overall size of the fiber bundle 31a increases, the individual filament groups composing the fiber bundle 31a will tend to move toward the direction in which the shaving blade 34a moves during shaving (the direction of the white arrow in Fig. 15), and therefore in order to prevent them from slipping under the shaving blade 34a it is necessary to bind their freedom of movement by the

embedding material 31b.

Also, as illustrated in Fig. 15, the shaving blade 34 provided on the blade stand 33 can be freely adjusted to protrude only by the protrusion length C from the contact plane A of the blade stand 33. For example, the protrusion length C may be freely adjusted to a height of less than 1 mm, and preferably 0.001-0.1 mm. The contact pressure transmitting member 35c forming part of the contact pressure applying means 35 can thus produce a condition wherein the shaving edge of the shaving material 31 is constantly pressed against the contact plane A of the blade stand 33 at the prescribed contact pressure. As a result, rotation of the shaving blade 34 provided on the blade stand 33 will allow ultrashort-cut fibers having fiber lengths of between 0.005 mm and 1 mm (especially fiber lengths between 0.005 mm and 0.1 mm) to be shaved from the shaving material 31 according to the adjusted protrusion length C. The thickness of the shaving blade 34 used is a matter of design to be appropriately optimized depending on the nature of the shaving material 31, but a thickness of 0.2-12.0 mm is suitable for use.

Adjustment of the protrusion length C of the shaving blade 34 will now be explained with reference to the embodiment shown in Fig. 16, where the adjustment of the protrusion length C is carried out using protrusion length adjusting means. In Fig. 16, the protrusion length adjusting means 37 comprises a sliding member 37a to which the shaving blade 34 is anchored, and an attachment member 37b such as a hexagon socket bolt, with the members 37a and 37b mounted as shown in an opening O provided in the blade stand 33. In Fig. 16, F is the sliding surface formed on the opening O of the blade stand 33, on which the sliding member 37a slides. H is a long hole for free movement of the sliding member 37a in the sliding direction when clamping of the attachment member 37b

is loosened. G is a groove in which the bottom of the sliding member 37a is fitted, and this groove is formed at the position shown in the opening O of the blade stand 33 along the direction of sliding of the sliding member 37a.

Since the protrusion length adjusting means 37 of the invention has a construction according to the embodiment shown in Fig. 16, loosening of the attachment member 37b, such as a hexagon socket bolt, using a tool such as a hexagonal wrench allows the sliding member 37a to slide freely in the direction of protrusion of the shaving blade 34 while being guided by the groove G. The shaving blade 34 can be adjusted to the prescribed protrusion length C by tightening the attachment member 37b with the protrusion length kept at the prescribed length C using a jig or the like. In Fig. 16, as mentioned above, one or more shaving blades 34 are provided on the blade stand 33 in the direction orthogonal to the plane of the paper, i.e. along the direction of the radius from the center of rotation (axial center of the rotary driving axis 36e).

The ultrashort-cut fiber production apparatus of the invention is used for shaving of a shaving material 31 to obtain ultrashort-cut fibers, as explained above, but prolonged shaving of the shaving material 31 can lead to gasification or liquefaction of the embedding material 31b when the operating environment for shaving is at a temperature higher than the solidifying temperature of the embedding material 31b, thereby preventing it from exhibiting its function. For this reason, it is necessary to provide insulating means (not shown) in the holding means 32 holding the shaving material, or cooling means (not shown) when insulating means alone is not sufficient, for adequate cold insulation to prevent gasification or liquefaction of the embedding material 31b. A preferred mode for achieving this object is to locally cool the periphery of the shaving

material 31 or to cool the entire shaving apparatus.

As mentioned above, cooling means is preferably provided for cooling of the shaving material according to the invention when the shaving material is shaved. Even if the shaving process is carried out under temperature conditions at which the embedding material 31b liquefies or gasifies, the cooling means cools the shaving material 31 to an appropriate temperature in order to maintain the embedding material 31 in a solid state with no phase conversion.

An embodiment of a ultrashort-cut fiber production apparatus equipped with such cooling means will now be explained with reference to Fig. 17.

Fig. 17 is a simplified schematic configuration diagram showing an embodiment of a ultrashort-cut fiber production apparatus according to the invention. In this diagram, 61 (61a and 61b) represent refrigerant pipes, 62 (62a and 62b) represent temperature sensors, 63 (63a and 63b) represent signal wires and 64 represents a refrigeration unit. The apparatus comprising the refrigerant pipes 61, temperature sensors 62, signal wires 63, refrigeration unit 64 and temperature controlling means (not shown) constitutes the cooling means of the invention.

The embodiment of cooling means of the invention shown in Fig. 17 will now be explained. The cooling means is provided with, for example, the refrigeration unit 64, and the refrigeration unit 64 is provided with a series of refrigerating devices such as a compressor, condenser and expansion valve as constituent elements. A refrigerant such as a fluorocarbon, fluorocarbon substitute, isobutane, ammonia, ethylene glycol or alcohol is circulated and distributed through each of the refrigerant pipes 61a and 61b in a refrigeration cycle to allow cooling of the shaving material 31 or shaving blade 34 to the required cooling temperature.

For the cooling, low-temperature gasifying gas may be caused to adiabatically expand for cooling and the cooled low-temperature gasifying gas may be directly distributed through the refrigerant pipes 61 with the refrigerant. For situations which do not require cooling to such a low temperature, a refrigerant such as brine may be subjected to primary cooling with the cooled low-temperature gasifying gas, and the primary cooled refrigerant such as brine may be circulated and distributed through the refrigerant pipes 61 for secondary cooling of the shaving material 31 and/or shaving blade 34. Conversely, when the shaving material 31 must be cooled to an even lower freezing temperature, a well-known liquefied gas such as liquid nitrogen or liquid oxygen may be produced by an established process and used as the refrigerant for circulated distribution through the refrigerant pipes 61.

The embodiment shown in Fig. 17 is an illustration of a system whereby the shaving blade 34 and the holding means 32 holding the shaving material 31 are cooling by contact with the refrigerant pipes 61a and 61b, but it will be readily imagined that a jacket may instead be provided around the exterior of the holding means 32 and the refrigerant circulated and distributed through the jacket. Alternatively, although the size of the apparatus will be increased, a refrigeration room having its internal atmosphere cooled to the optimum temperature may be prepared for cooling of the entire shaving apparatus including the shaving material 31 and shaving blade 34 in the refrigeration room, or only the sections requiring cooling may be subjected to local cooling.

As explained above, the shaving material 31 is cooled by cooling means according to the invention, and preferably the shaving blade 34 is simultaneously cooled together with the shaving material 31, as already described. This is because when the shaving material 31 is continuously shaved for a

prolonged period, increasing temperature of the shaving blade 34 due to friction with the shaving material 31 can have adverse effects such as blunting of the cutting edge of the shaving blade 34, notable abrasion of the shaving blade 34, or changes in the fiber lengths of the shaved ultrashort-cut fibers during shaving due to changes in the protrusion length of the shaving blade as a result of thermal expansion and the like.

When a relatively low molecular weight resin or paraffin is used as the embedding material 31b having a melting point of 10-150°C, the softness of the embedding material 31b will produce a situation in which the fiber bundle 31a cannot be firmly bound by the embedding material 31b. In such cases as well, the hardness of the embedding material 31b can be controlled by cooling the shaving material 31 by the aforementioned cooling means to achieve freezing to, for example, between 0°C and -100°C. This will allow the hardness of the embedding material 31b to be controlled to create a condition where the freedom of movement of the fiber bundle 31a is satisfactorily restricted by the embedding material 31b. In this case, the temperature suitable for freezing of the shaving material 31 will differ depending on the embedding material 31b used, and therefore the final optimum temperature is preferably determined by experimentation with an actual shaving process.

The cooling temperature thus determined by experimentation is stored in the storage means of the temperature controlling means, comprising a microcomputer or the like not shown here, and is used to achieve cooling to the optimum state for the shaving material 31 or shaving blade 34. The temperature control is accomplished, for example, using a temperature sensor 62a comprising a temperature sensing element such as a thermocouple mounted on the holding member

14 which holds the shaving material 31, or using a similar temperature sensor 62b mounted on the shaving blade 34 or on an anchoring member 5 anchoring it, to detect the temperature of the shaving material 31 and the shaving blade 34, and using the detected temperature as the control variable for input to the temperature control means via interface means provided with a transducer or A/D (analog/digital) converter or the like. The inputted detected temperature is used as the basis of feedback control of the refrigeration unit by an established method to keep the shaving material 31 or shaving blade 34 at the optimum temperature which is determined by experimentation as mentioned above.

The cooling means used for the invention is not restricted to the system described above employing a refrigerant, as other types of systems may also be used. For example, a different type of cooling system may be employed whereby cooling is accomplished utilizing a Peltier element such as illustrated schematically in Fig. 18. In Fig. 18, 65 is a Peltier element, 66 is a heat sink, 67 is electrical wiring for the Peltier element, and 68 is a thermal insulating material. As a simplified explanation of the Peltier element 65, this Peltier element 65 is an element which utilizes the "Peltier effect" to convert electric power to heat energy by flowing a current between elements, whereby it can function for control of temperature. It generally has a construction wherein a p-type thermoelectric transducer and an n-type thermoelectric transducer are alternately connected by electrodes while the electrode surfaces are gripped by an insulating material, and it offers the advantages of a simple construction and easy handling.

Thus, by using the Peltier element 65 having this feature in connection with the heat-releasing shaving blade 34, it is possible to draw heat from the shaving blade 34 and release it

from the heat sink, in order to eliminate generated heat energy from the shaving blade 34. This will allow the shaving blade 34 to be held at a constant temperature, and thus contribute to stable shaving performance of the shaving blade 34. Here, the shaving blade 34 is preferably anchored to the anchoring member 37 via the thermal insulating material 68, because this will render it thermally separate from the anchoring member 37 and allow control of the temperature of the shaving blade 34 to the prescribed temperature even using a Peltier element 65 with only medium cooling power. The temperature control of the shaving blade 34 may be accomplished by inputting the temperature detected by the temperature sensor 62b mounted on the shaving blade 34 to the temperature control means (not shown) through the signal wire 63b, and conducting feedback control of the current supplied to the Peltier element via the electrical wiring 67.

The shape of the shaving material 31 held by the holding means 32 is not limited to cylindrical, and may be any other shape such as square columnar, hexagonal columnar, oblong columnar or the like, or even columnar with a donut-shaped lateral cross-section. The shape will depend on the conditions during embedding treatment of the fiber bundle 31a by the embedding material 31b. For example, when the paralleled fiber bundle 31a and water are placed in a pot (freezing vessel) and the water in the pot is frozen for embedding treatment, the shape of the shaving material 31 will be governed by the shape of the pot. It will also differ depending on the conditions of the holding member 32a of the holding means holding the shaving material 31.

Instead of the embodiment described above for the apparatus for production of ultrashort-cut fibers of the invention, wherein the shaving edge of the shaving material 31 is constantly pressed at a prescribed contact pressure against

the contact plane A formed on the top side of the blade stand 33 for shaving with the shaving blade 34a, the following embodiment may also be employed.

In the following embodiment, the shaving material 31 is forcefully fed against the shaving blade 34a by the prescribed amount corresponding to the fiber length to be shaved from the shaving material 31, for shaving with the shaving blade 34a, instead of pressing the shaving edge of the shaving material 31 at a prescribed contact pressure against the contact plane A formed on the top side of the blade stand 33. After the shaving edge of the shaving material 31 has been shaved by the shaving blade 34a, the shaving material 31 is again forcefully fed against the shaving blade 34a by the prescribed amount corresponding to the fiber length to be shaved from the shaving material 31, before the next shaving begins for shaving with the shaving blade 34a, and this procedure is repeated. As the means for carrying out this function, the apparatus of the invention is provided with feeding means for intermittent feeding of the shaving material against the shaving blade 34a by a prescribed amount corresponding to the fiber length to be shaved.

As the specific construction of the feeding means there may be employed a well-known technique commonly used in shaving machine tools for feeding the shaving blade 34a and/or the shaving material 31 by a prescribed amount. The detailed explanation thereof will be omitted here. As one example, however, there may be provided a holder which firmly holds the shaving material 31 without slipping. The holder is attached to a shaft having a helical feed groove. This is well-known intermittent feeding means whereby rotation of the shaft by a prescribed rotation angle allows the shaving material 31 to be intermittently fed against the shaving blade 34a by the prescribed amount. A servo motor such as a pulse motor may be

used for rotation of the shaft by the prescribed rotation angle.

In the embodiment described above, the shaving edge is contacted with the shaving blade 34a between shavings, instead of constantly contacting the shaving edge of the shaving material against the contact plane A of the blade stand 33, thereby offering an advantage whereby the shaving edge of the shaving material 31 is less affected by vibration of the blade stand 33 or the shaving blade 34a generated by friction or during shaving.

Since it is an object of the present invention to provide a process for satisfactorily producing ultrashort-cut fibers by shaving with improved production efficiency, an embodiment thereof will now be explained in detail with reference to Figs. 19 and 20. Figs. 19 and 20 are schematic illustrations showing production of ultrashort-cut fibers according to the invention.

When cutting out ultrashort-cut fibers of 0.005-1.0 mm from the fiber bundles 31a, shaving of the shaving material 31 is preferably carried out while holding the shaving material 31 with the holding means 32 at a position close to the shaving blades 34. This will make it possible to avoid deformation of the embedding material 31b by impact force during the shaving as occurs with ice or dry ice, or concentration of the force during shaving on the anchor section, for materials prone to damage. Therefore, it is essential for the holding means 32 performing this role to be provided with the function of supporting or holding the shaving blade 34 which moves relative to the shaving material 31 in the direction indicated by the white arrow in the drawing.

Thus, the holding means 32 performs the role of distributing and absorbing the force acting on the shaving

material 31 at a position close to the shaving blades 34 during shaving. The holding means 32 may also consist of a jig such as a guide plate which contacts with the shaving material 31, so that it does not completely hold the shaving material 31 but rather supports the shaving material 31 from the direction opposite to the direction of the shaving force acting on the shaving material 31. The member holding and anchoring the shaving material 31 may be a known chuck so long as it can satisfactorily hold and anchor the shaving material 31. However, if it is desired to more firmly grip and anchor the shaving material 31, the lower end of the fiber bundle 31a forming part of the shaving material 31 may be solidified with a resin such as an adhesive, and the resin section held and anchored.

According to the process of the invention, ultrashort-cut fibers are produced by shaving the edge F of a shaving material 31 composed of embedded fiber bundles, and specific examples of apparatuses for shaving of the shaving material include apparatuses with shaving mechanisms employed in known machine tools such as planing machines, slotting tools, planing/molding machines and millers. However, while such well-known apparatuses may be appropriated directly for the invention, the mechanisms or constructions of such known machining tools may also be partly modified.

In particular, wherein using a planing machine or the like, the workpiece (according to the invention, this is the "shaving material 31 comprising the fiber bundles 31a embedded in the embedding material 31b") mounted on the working bench is a single continuous block, as is the case when planing a rail, for example, but according to the present invention, a plurality of individual independent shaving materials 31 must be situated in an array in the direction of planing. According to the invention, however, a plurality of shaving

materials 31 may even be set in parallel in a dense state and embedded in the embedding material, thereby forming a single block which may be supplied to the working bench.

An embodiment of producing ultrashort-cut fibers with substantially the same mechanism as a known planing machine incorporated as part of the construction of the ultrashort-cut fiber producing apparatus will now be explained.

Fig. 19 shows an embodiment wherein numerous shaving materials 31 are set in an array on the working bench, and the edges F of the fiber bundles 31a embedded in the embedding material 31b are shortly shaved by shaving the shaving materials 31 to obtain ultrashort-cut fibers. Fig. 19 shows an example with column 1 (R1) to column 16 (R16) in the horizontal direction and row 1 (L1) to row 8 (L8) in the vertical direction for a total of 128 (8 x 16) shaving materials 31 set on a working bench, but the invention is naturally not restricted to this number or arrangement so long as the gist of the invention is satisfied.

Here, it is essential that the group of shaving materials 31 forming the shaving edges F which are orthogonal to the lengthwise direction of the fibers are set so that all of the shaving edges F are level. This is because the shaving edges F become leveled when at least one of the shaving blades 34 shaves a group of shaving materials 31. However, the shaving edges F do not necessarily have to be leveled before planing of the shaving materials 31 begins. Even if uneven shaving edges F are formed before planing, rough cutting of the shaving edges F can be carried out to produce a horizontal surface from the shaving edges F of the shaving material 31. Still, the rough cut sections will have uneven shaven fiber lengths, and must therefore be removed before the actual planing so that they do not mix with the ultrashort-cut fiber products.

If a plurality of shaving materials 31 are prepared and set on the working bench (not shown) in the array shown in Fig. 19, simultaneous shaving of the edges F of the shaving materials 31 will naturally result in a major improvement in ultrashort-cut fiber yield compared to shaving individual shaving materials. As already explained above, the plurality of shaving materials 31 may also be set in an arrangement without spaces, and a group of the plurality of shaving materials 31 in a dense array may be embedded in an embedding material filling the spaces between each of the individual shaving materials 31 and integrated, to obtain a "new shaving material". Also, the "new shaving material" may be subjected to planing using a known planing machine to mass produce ultrashort-cut fibers having ultrashort-cut fiber lengths of 0.005-1.0 mm.

Incidentally, while Fig. 19 shows an example of mass production of ultrashort-cut fibers by aligning a plurality of shaving materials 31, efficiency of the ultrashort-cut fiber production can be improved by setting up an array not only of a plurality of shaving materials 31 but rather of a plurality of shaving blades 34, as with the embodiment shown in Fig. 20. Fig. 20(a) is schematic front view and Fig. 20(b) is a schematic side view. In this embodiment, the plurality of shaving materials 31 is shaved at once by shaving blades 34 set on sixteen (4 x 4 in the longitudinal and lateral directions) blade stands 33, to accomplish mass production of ultrashort-cut fibers.

The degree of protrusion of the shaving blades 34 with respect to the shaving materials 31 is adjusted, however, for movement of the shaving blades 34 in the lateral direction, or in the direction indicated by the white arrow as shown in Fig. 20(b). For example, in Fig. 20(b), the shaving blade 34 which shaves the shaving material 31 at position R7 is formed to

protrude toward the shaving materials 31, with respect to the shaving blade 34 which shaves the shaving material 31 at position R8, by an amount corresponding to the intended fiber length of the ultrashort-cut fibers. The same relationship applies for the shaving blades 34 which shave the shaving materials 31 at positions R9 and R10 in Fig. 20(b).

A process for production of ultrashort-cut fibers according to the invention will now be explained by a working example.

First, an individual filament group made of polyester was bound into a 2 million dtex fiber bundle, and the fiber bundle was immersed in a potassium filled with water and frozen to obtain a shaving material with ice as the embedding material. The shaving edge of the obtained shaving material 31 was cut with a rotary cutter having a circular cutting blade to produce a φ75 mm x 40 mm length cylindrical shaving material 31 having clean shaving edges. The same type of apparatus shown in Fig. 14 was used to clamp the shaving material 31 with a clamping member comprising a pair of half cylinders. The clamping member forming part of the holding means 32 was surrounded by a jacket through which a refrigerant (brine) circulated, so that the holding means 32 was cooled to -4°C.

Next, an air cylinder with a φ50 mm cylinder diameter and a 100 mm stroke length was employed as contact pressure applying means 35 and compressed air at 0.11 MPa was fed to the air cylinder to press the shaving material 31 against the contact plane A of the blade stand 33. The rotation driving axis (blade stand 33) was also rotated at 30 rpm by a reduction gear-equipped inverter motor via a timing belt. Here, the shaving blade 34 used was high speed steel with a thickness of 0.25 mm, a blade mounting angle of 25° and a back angle of 30°. The protrusion length of the shaving blade 34 was adjusted to 0.02 mm for shaving, yielding ultrashort-cut

fibers with fiber lengths of 0.025 mm. After eliminating the water from the obtained ultrashort-cut fibers, they were dried in a conventional hot air drier using hot air at 120°C. The shaved ends of the dried ultrashort-cut fibers were clean, with virtually no miscut short fibers.

Ultrashort-cut fibers obtained by the production process of the invention are shaved to fiber lengths of 0.005 mm to 1 mm, and especially 0.005 mm to 0.1 mm, and therefore they are expected to have a wide range of uses including, for example, use in paints by inclusion of ultrashort optical interference fibers in an adhesive such as described in Japanese Unexamined Patent Publication HEI No. 11-241223, use by inclusion in cosmetic products, or use for flock working or as a printer toner material.

Moreover, the production apparatus of the invention can easily and stably produce ultrashort-cut fibers having fiber lengths of 0.005 mm to 1 mm, and especially 0.005 mm to 0.1 mm, while drastically reducing miscut fibers, and therefore provides satisfactory product yields to allow production of ultrashort-cut fibers on an industrial scale.